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Combining Additive Manufacturing and Vacuum Casting for an Efficient Manufacturing of Safety Glasses

This paper presents the possibility of integration of modern techniques of additive manufacturing and vacuum casting in the rapid manufacturing of complex parts. The prototype of safety glasses was directly developed from a CAD model, which is used as a main model for making moulds in a vacuum casting process. The development stages, which include additive production of glasses and the process of vacuum casting with the definition of material components, preheating temperature, the forming of silicone mould, the casting process, hardening and other parameters are presented in this paper. It is proved that by using this technique it is possible to produce complex functional parts quickly, with high precision, accuracy and surface quality, while significantly reducing costs of development and production compared to other similar technologies.

Keywords: *Additive manufacturing, Vacuum casting, Rapid prototyping, safety glasses*

1. INTRODUCTION

The more time spent on the product development, the more opportunities for profit are lost. It is this philosophy that drives many industries during the development of new products [1]. Recognizing the need to create more prototypes of the same part, efforts have been made to develop a cost-effective system of rapid prototyping of replicas of parts. This system would allow users to check design, quality and other tests before the start of mass production and presentation of products on the market. Thus, this method of rapid production combines two manufacturing processes, rapid prototyping and rapid tooling.

a. Requirements and need for an integrated system

Rapid prototyping technology, as well as many other technologies, has a range of limitations [2]. Limits in usage of rapid prototyping techniques are mainly related to high costs of using these systems. These costs are generally related to the purchase, amortization and maintenance of RP systems, the cost of materials and the cost of involvement of qualified personnel. In addition, one of the main drawbacks of RP technique is a limited number of materials that are used, since each of the RP techniques generally uses a specific type of material. In the actual case, a 3D printer, based on the principle of extrusion materials (Fused Deposition Molding - FDM).

This material is often not the same or even similar to the material that a finished product needs to be made of. Also, mechanical and physical properties of the material generally do not coincide with the characteristics of the material a final product should be made of [3-5]. For functional and final testing, of the utmost importance is that the physical and mechanical properties of the material used for making prototypes are the same or at least close to the characteristics of materials that will be used to produce the final product, which is a requirement that the materials used by the RP systems often do not meet. At the stage of development and design of the product, when performing basic analysis and opinions, it is often required to use a certain number of identical prototypes for testing. At this stage, therefore, it is necessary to produce a small series of identical prototypes, which, using the 3D printer, can be very slow, costly and inefficient. This is another shortcoming of RP techniques, and it also reveals the need to develop a system that will allow the production of small series of identical prototypes. The alternative is an integrated system which will use the 3D printer to produce a prototype of the product, which would be used in the next step as a master model for tools that would produce a series of prototypes, i.e. products made of different materials, with characteristics close to the finished product. The integrated system of rapid prototyping and rapid tooling, in this case the technology of vacuum casting and 3D printers based on the principle of FDM (Fig.1.), shall satisfy the needs and requirements of engineers [6-9]. Engineers perform the assessment of the functionality and characteristics of the prototype that needs to satisfy the following requirements:

- The prototype should look like the final product in terms of dimensional accuracy, surface quality and colour.
- It should be made of materials with the same or similar characteristics as the final product to be tested in real working conditions. Also, there should be no voids in the internal structure.

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- The prototypes should be made in sufficient quantities to facilitate and accelerate the process of design optimization and should be mutually equal.

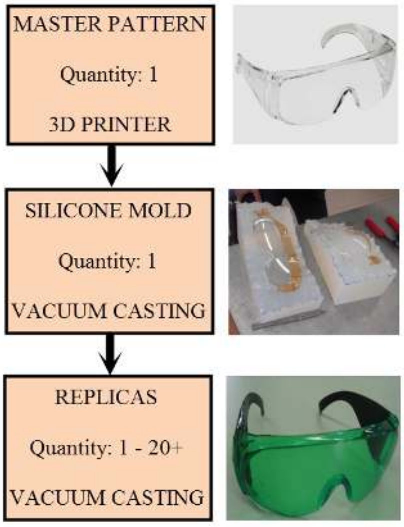


Figure 1: An integrated system

2. THE ROLE OF 3D PRINTING IN AN INTEGRATED PROCESS

The RP technique, which was used in a specific case for making master models of safety glasses, is a 3D printer based on FDM principle (Stratasys - Dimension Elite), which plays a key role in the integrated process. Of great importance is the accuracy that is achieved in this 3D printer, during which it is necessary to pay special attention to the positioning and orientation of the master model on platform [6]. The procedure that has been necessary to obtain a master model or prototype of safety glasses is as follows:

- Product design in some of the CAD software packages,
- Conversion of CAD models in STL format that is recognized by a 3D printer,
- Transfer of STL files to the computer that controls the three-dimensional printer,
- Processing of STL files within the CatalystEX program in which all the parameters are set and adjusted according to the required model,
- Creating a three-dimensional model using additive technology [10] and
- Further processing of created prototypes.

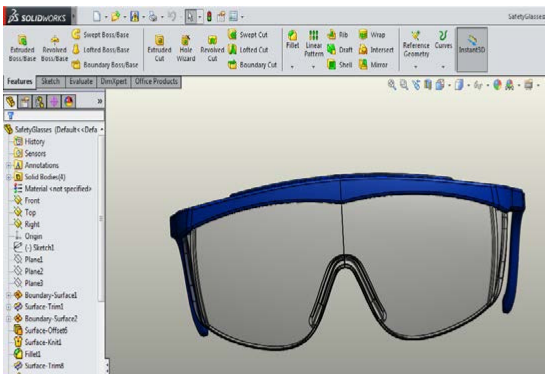


Figure 2: A model of safety glasses in the Solid Works software package

The layout of model of safety glasses designed in SolidWorks software package is shown in Figure 2 and parameter adjustment within the CatalystEX, where the selection of the orientation of models, processing of layers and layout of models on a base on which printing on a "Dimension Elite" 3D printer will be performed, is shown in Figure 3.

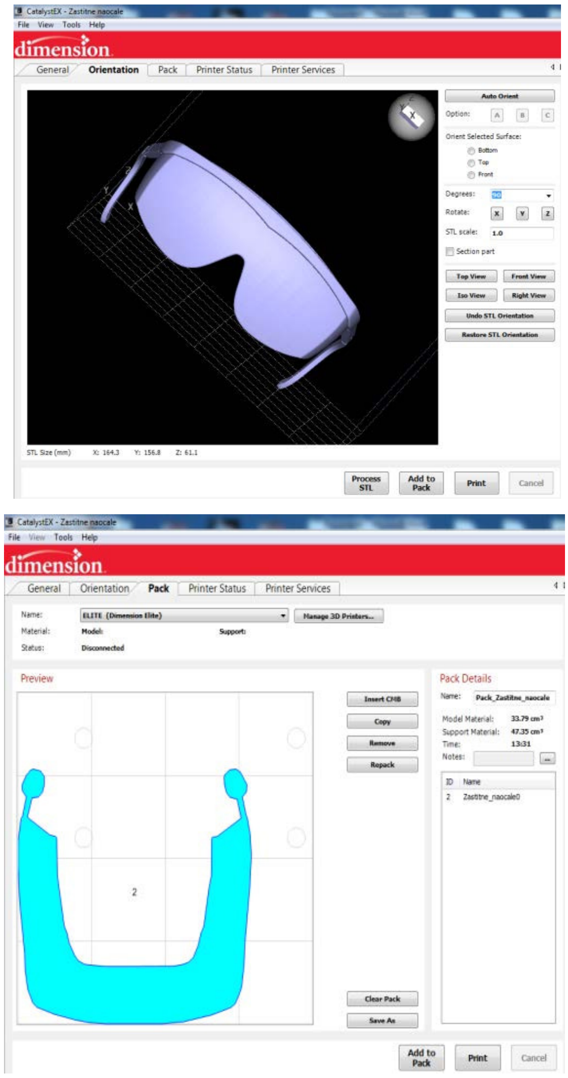


Figure 3: Orientation and processing of models in Catalyst-EX

3. THE ROLE OF VACUUM CASTING IN AN INTEGRATED PROCESS

The technology of vacuum casting has become a widely accepted rapid tooling technique. Vacuum casting is a newer version of investment casting, differing in the process of making moulds [11-13]. The most important feature of vacuum casting is a significant reduction in the time needed to produce a small series of parts as well as reducing the cost compared to traditional methods. The example of making silicone molds and casting replicas of safety glasses according to the master model developed in a 3D printer, on the equipment for vacuum casting (MK-Technology, Germany) is used to present the process of vacuum casting [14,15].

The process of vacuum casting consists of the following steps:

1. Preparation of negatives of safety glasses produced

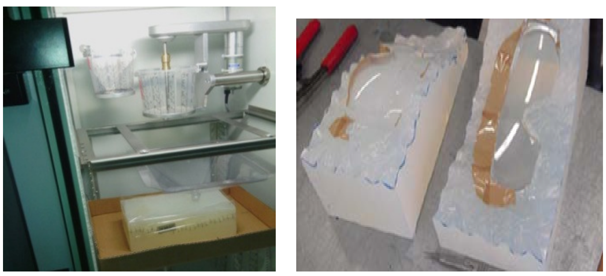
on a 3D printer for the casting process.

2. Setting the parting tape on the negative of safety glasses that will facilitate the separation of silicone mould.
3. Bonding plastic gates on the negative of safety glasses which has a role to form an inlet channel in the silicone mould and to facilitate the positioning and fixation of the negative in the silicone casting frame, according to Figure 4a.
4. Calculation of the necessary quantity of silicone mixture to form a silicone mould to be used for detail the elements of safety glasses. The silicone mixture is poured into the frame with fixed negatives of safety glasses and then the frame with the negative submerged in silicone is placed in a vacuum chamber in order to remove the residual air bubbles from silicon, according to Figure 4b.

a) b)

Figure 4: (a) Casting silicone into the frame with the negative, and (b) removing the residual air from the silicon in a vacuum chamber

5. Positioning of the silicone mould in a vacuum chamber (Figure 5a). After solidification of silicone, silicone mould is cut to parting line, during which we relieve the negative and get a silicone mould for casting a replica of a given negative (Figure 5b).
6. The moulding halves are then combined and the next step is to calculate necessary quantities of resin for moulding elements of safety glasses. The amount of resin is commonly determined by weighing the individual master model, which is increased by 20-30%, taking into account the loss of material in vessels and inlet channels. In this case, to cast the wings of safety glasses, components made by Axson Technologies were used, thus by mixing them in the casting process parts with physical and mechanical characteristics according to Table 1 and Table 2 are obtained.



a) b)

Figure 5: a) Positioning a silicone mould in a vacuum chamber and b) Separated silicone mould

Table 1: Physical characteristics of components used for casting wings of safety glasses

PHYSICAL PROPERTIES PX 223 HT				
		PART A	**PART B**	**MIXING**
Composition		**ISOCYANATE**	**POLYOL**	
Mixing ratio by weight		100	80	
Aspect		liquid	liquid	liquid
Colour		colourless	black	black
Viscosity at 77°F (25°C) (mPa s)	BROOKFIELD LVT	1.100	300	850
Density of parts before mixing at 25°C	ISO 1675:1975	1.17	1.12	-
Density of cured mixing at 23°C	ISO 2781:1988	-	-	1.14
Pot life at				6-7

Table 2: Mechanical characteristics of components used for casting wings of safety glasses

MECHANICAL PROPERTIES AT 23°C PX 223 HT			
Flexural modules of elasticity	ISO 178:2001	MPa	2.300
Flexural strength		MPa	80
Tensile strength	ISO 527-2:1993	MPa	60
Elongation		%	11
Charpy impact resistance	ISO 179/2D:1994	kJ/m^2	>60[1]
Izod Impact - Notched	ASTM D256-05	kJ/m^2	6
Izod Impact - Unnotched	ASTM D256-05	kJ/m^2	16[1]
Hardness - at 73°F (23°C) - at 248°F (120°C)	ISO 868:2003	Shore D1	80 >65

For casting protective glass of glasses are also used components of manufacturers Axson Technologies which mixed in casting process allows for obtaining parts with characteristics such as transparency, high precision, good UV protection and convenience for finishing, according to Table 3 and Table 4.

Table 3: Physical characteristics of components used for casting the protective glass of glasses

PHYSICAL PROPERTIES PX 223 HT				
Composition		**ISOCYANATE PX 521HT A**	**POLYOL PX 521 HT B**	**MIXING**
Mixing ratio by weight		100	80	
Aspect		liquid	liquid	liquid
Colour		Transparent	Bluish	transparent
Viscosity at 25°C (mPa s)	BROOKFIELD LVT	200	1.100	500
Density at 25°C	ISO 1675:1975	1.07	1.05	-
Density of cured mixing at 23°C	ISO 2781:1988	-	-	1.06
Pot life at 25°C on 155 g (min)				20

Table 4: Mechanical characteristics of components used for casting the protective glass of glasses

MECHANICAL PROPERTIES AT 23°C PX 223 HT			
Flexural modules of elasticity	ISO 178:2001	MPa	2.100
Flexural strength		MPa	105
Tensile modulus of elasticity	ISO 527-2:1993	MPa	2.700
Tensile strength		MPa	75
Elongation at break point in tenstion		%	9
Charpy impact resistance	ISO 179/1eU:1994	kJ/m^2	27
Izod Impact - Notched	ASTM D256-05	kJ/m^2	6
Izod Impact - Unnotched	ASTM D256-05	kJ/m^2	17
Hardness	ISO 868:1965	Shore D1	87

7. After a certain quantity of the material needed for moulding and the proportion of the individual components of the material in a total amount is determined, then vacuum casting process follows. The casting process takes place in a vacuum chamber under conditions that are recommended for corresponding elements and components of the material, according to Figure 6.

Figure 6: The casting process in a vacuum chamber MK-Technology

8. After solidification of the moulded material in a vacuum chamber, mould halves are separated and, if necessary, post-processing of the moulded item follows.

Different safety glasses were made in the integrated process of additive manufacturing technology and vacuum casting in the Laboratory for Plasticity and Processing Systems at the Faculty of Mechanical Engineering in Banja Luka and at the Department of Industrial Engineering at University of Bologna, where result of this study are shown in Figure 7.

Figure 7: Safety glasses made in the integrated process of additive manufacturing technology and vacuum casting

4. CONCLUSIONS

The development of safety glasses through the integration process of additive manufacturing and vacuum casting shows an example of a very successful application of modern technology in the rapid development of prototypes and production small series of identical prototypes. Prototypes can be made from the original material that can be very broad spectrum in terms of physical, technical and mechanical properties. Considering that this integrated technology has applications in many industrial fields such as automotive, aerospace, pharmaceutical, medical, food industry and others, an example of creating safety glasses confirms its application to very complex elements in these areas. The design of safety glasses yielded specific characteristics such as good surface quality, satisfactory physical appearance, transparency, rigidity, elasticity, strength, hardness, temperature resistance, UV stability, colour and so on. In terms of cost and time of production, it has been proven that these parameters were significantly reduced compared to the comparative technology. As demonstrated in several studies (as in [16]), the additive manufacturing can represent the right option for a large gamma of industrial products. Furthermore, additional savings could be realized using an integrated approach for the full cost optimization of the process as a whole, instead of moving toward single steps of reduction for additive manufacturing and, separately, vacuum casting.

Finally, the benefits provided by these new techniques toward a modern manufacturing has to be also considered in term of eco-sustainability, evident when compared with conventional methods ([17]).

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КОМБИНАЦИЈА АДИТИВНЕ ПРОИЗВОДЊЕ И ВАКУУМ ЛИВЕЊА ЗА ЕФИКАСНУ ПРОИЗВОДЊУ ЗАШТИТНИХ НАОЧАРА

М. Шљивић, А. Павловић, М. Станојевић, К. Фрагаса

Овај рад приказује могућност интеграције савремених техника адитивне производње и вакуум ливења у брзој производњи сложених делова. Прототип сигурносних наочара је директно развијен из ЦАД модела, који се користи као главни модел за израду калупа у процесу вакуум ливења. У овом раду приказана је развојна фаза, која укључује адитивну производњу наочара и процес вакуум ливења са дефинисањем материјала компонента, предгревање температуром, формирање силиконских калупа, процес ливења, каљење и друге параметре. Доказано је да је могуће помоћу ове технике произвести сложене функционалне делове брзо, са високом прецизношћу, тачношћу и квалитетом површине, док су трошкови развоја и производње у односу на друге сличне технологије значајно смањени.